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**Development of a Definite
Wave-Point Closing Switch**

Electrical Engineering

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DEVELOPMENT OF A DEFINITE
WAVE-POINT CLOSING SWITCH

BY

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B. S. University of Illinois, 1912

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN ELECTRICAL ENGINEERING

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1913

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THE GRADUATE SCHOOL

May 31 1913

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Glen David Bagley

ENTITLED Development of a Definite Wave-Point Closing Switch.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Science in Electrical Engineering

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Morgan Brooks
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Oliver Paine

Committee

on

Final Examination



TABLE OF CONTENTS.

I. Introduction.....	1
II. Construction of Switch.....	2
III. Tests of Switch.....	4
IV. Design and Construction of Relay.....	6
V. Tests of Switch and Relay.....	6
VI. Measurement of Armature Reactance by Switch...	7



THE DEVELOPMENT OF A DEFINITE WAVE-POINT CLOSING SWITCH.

I.

The function of a definite wave-point closing switch is to close an alternating-current circuit at any predetermined instant, i.e. at any phase angle from the neutral point of the electromotive-force wave. It differs thus essentially from a contact-maker which makes a momentary contact usually at every cycle or revolution of the alternator. A definite wave point switch closes the circuit and maintains the contact until it is broken by some extraneous means.

Such a switch is of great value in the study of all forms of transient phenomena since the magnitude of the transient always depends upon the phase angle of closing of the circuit. An ordinary switch will close the circuit at any point of the electromotive-force wave and such random closings give results which are necessarily very difficult to interpret and analyze. Various switches have been designed to close the circuit at any desired wave point, but the results have not been satisfactory on account of their erratic operation.

The design of a switch which would be accurate within at least five electrical degrees was the object of the undergraduate thesis of the writer in 1912. The construction of the device was not completed then. The finishing of the switch and its development to the point where results of the required

degree of accuracy were obtained, together with the tests, form the subject matter of the present thesis.

II.

The fundamental feature of this device is an insulated drum A, Plate I-A, driven from the shaft of the alternator. A part of this drum is covered by a brass cylinder B, the end of which is cut in a helix. A carriage C, carrying a contact roller D, is driven by a screw E, which engages a split nut F, at such speed that its axial motion along the drum is the same as that which would be given to a point moved axially by the helix on the end of the brass cylinder. This motion is attained by making the pitch of the screw E one-half that of the helix and driving it by the two to one gears M and N. When this condition is obtained the circuit can be closed only when the contact roller D meets the axial line G connecting the ends of the helix. With the roller in any fixed angular position on the drum, this can only occur when the armature or rotating field of the alternator is also in a certain definite angular position, and consequently when the phase of the electromotive-force wave has a definite value which is the feature desired in making short circuit and other tests.

An insulated brush carries the current to the brass cylinder B and the roller D is supported in insulated bushings. The contact with the roller is made by a flexible cord which may be seen in Plates II and III. The portion A of the drum is covered by another brass cylinder in order to provide a smooth surface for the roller to run upon. This drum fits up

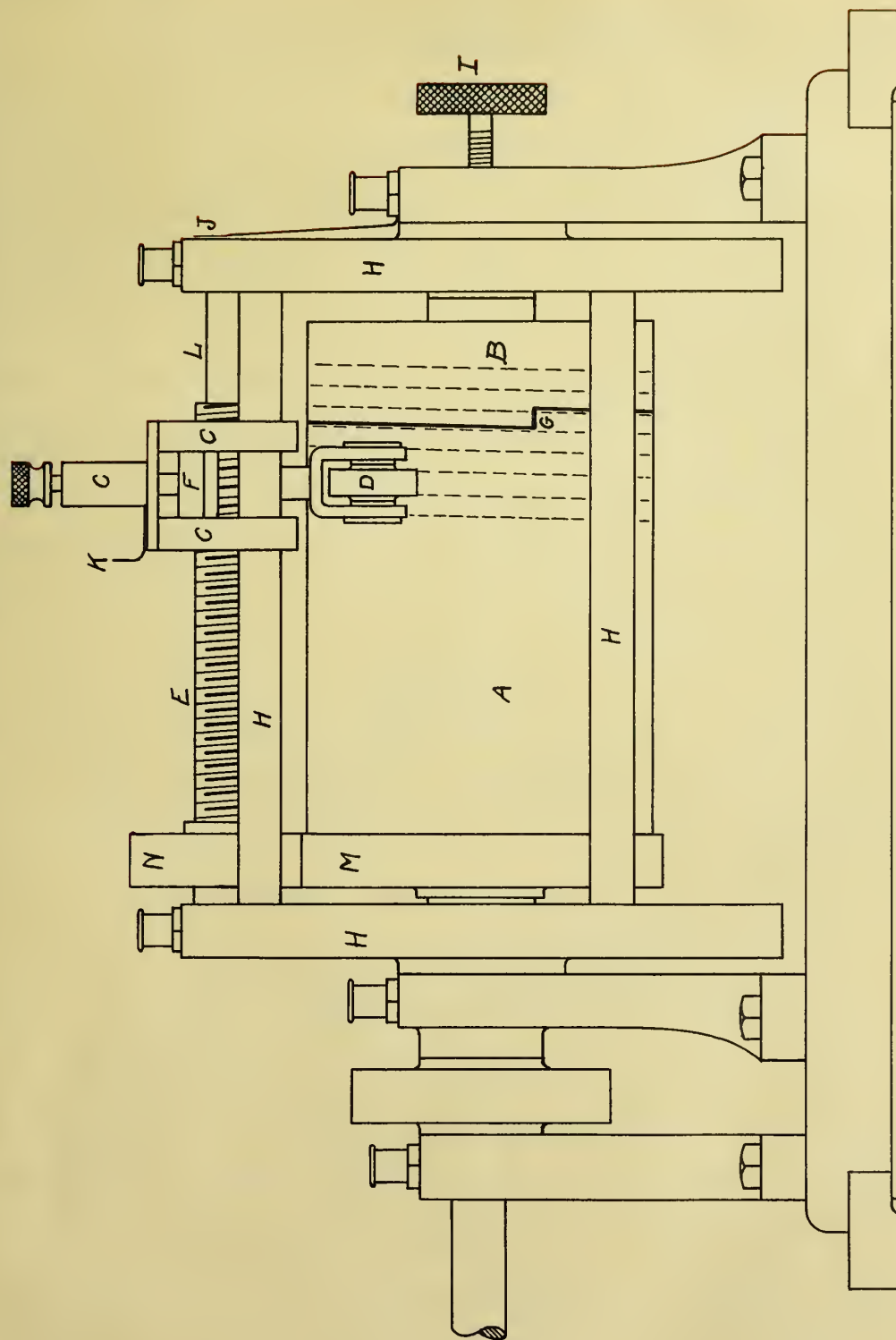


PLATE I-A
Side view of switch.

against the contact drum B and is insulated from it by a piece of sheet fiber.

The method of operation of the machine is to set the frame H upon which the carriage C moves at any angle desired. The frame is held in this position by the set screw I, and the angle is measured by the pointer J and a graduated circle on the end of the frame H. The split nut F is then raised and the carriage C moved to the left end of the rods upon which it slides. When it is desired to close the circuit the nut is dropped down upon the screw by pulling out the catch K. The nut F engages the screw E and the carriage moves to the right. The path which the roller traces upon the revolving drum is shown by the dotted line which also shows how the contact is made at G. After the contact is made the nut F runs off the thread onto the smaller portion of the shaft L and the carriage stops. Since the roller is now on the portion B of the drum which is connected to the circuit the contact is maintained.

The apparatus was designed to run at the same speed as that of a four pole alternator for any frequency up to sixty cycles. At this frequency the drum runs at 1800 R.P.M., which is the maximum speed at which it should be run. A set of change gears was provided so that the drum would still run at the same speed when attached to alternators with a number of field poles other than four. This was necessary in order to keep the value of an actual degree in terms of electrical degrees constant so that the same angular measuring device could be used. It was also necessary in order to keep the drum from running at too

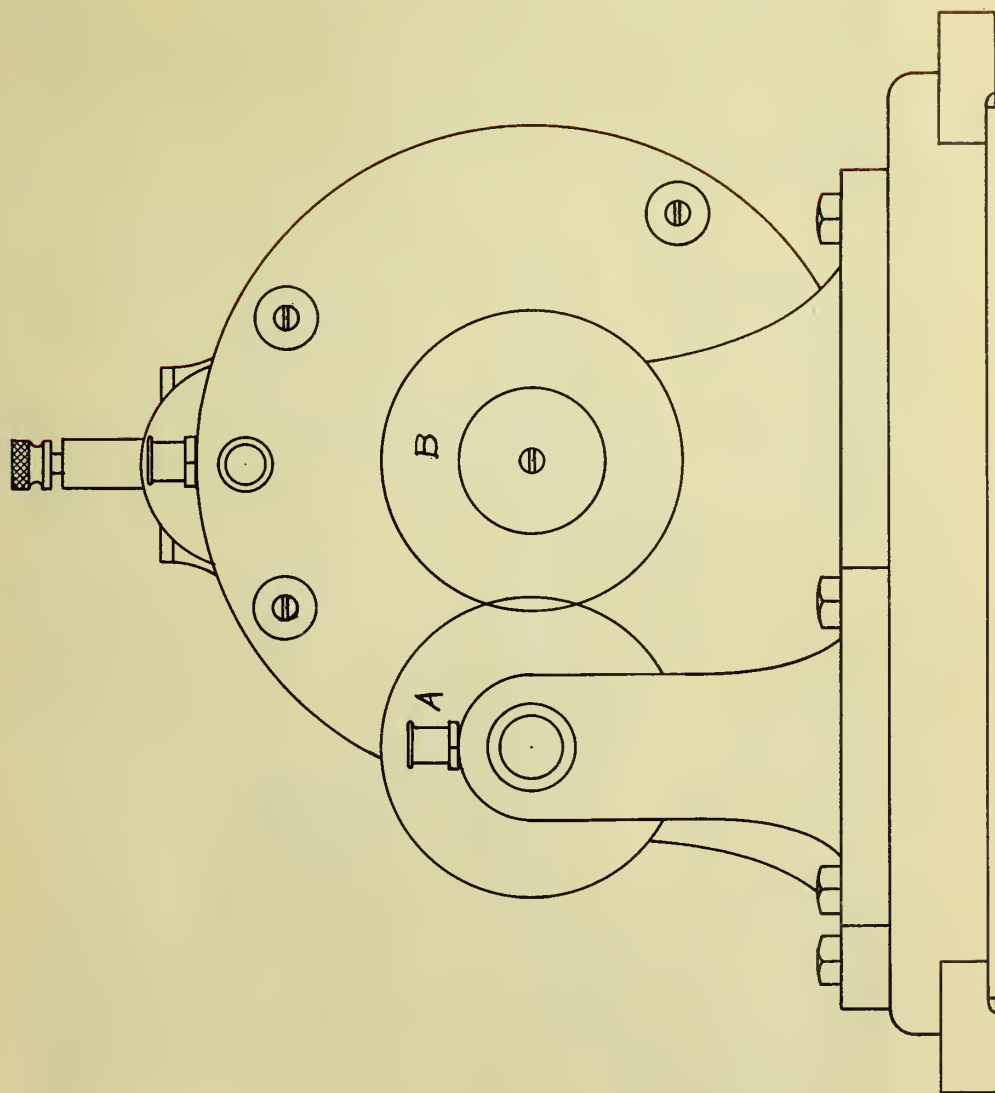


PLATE I-B
End view of switch.

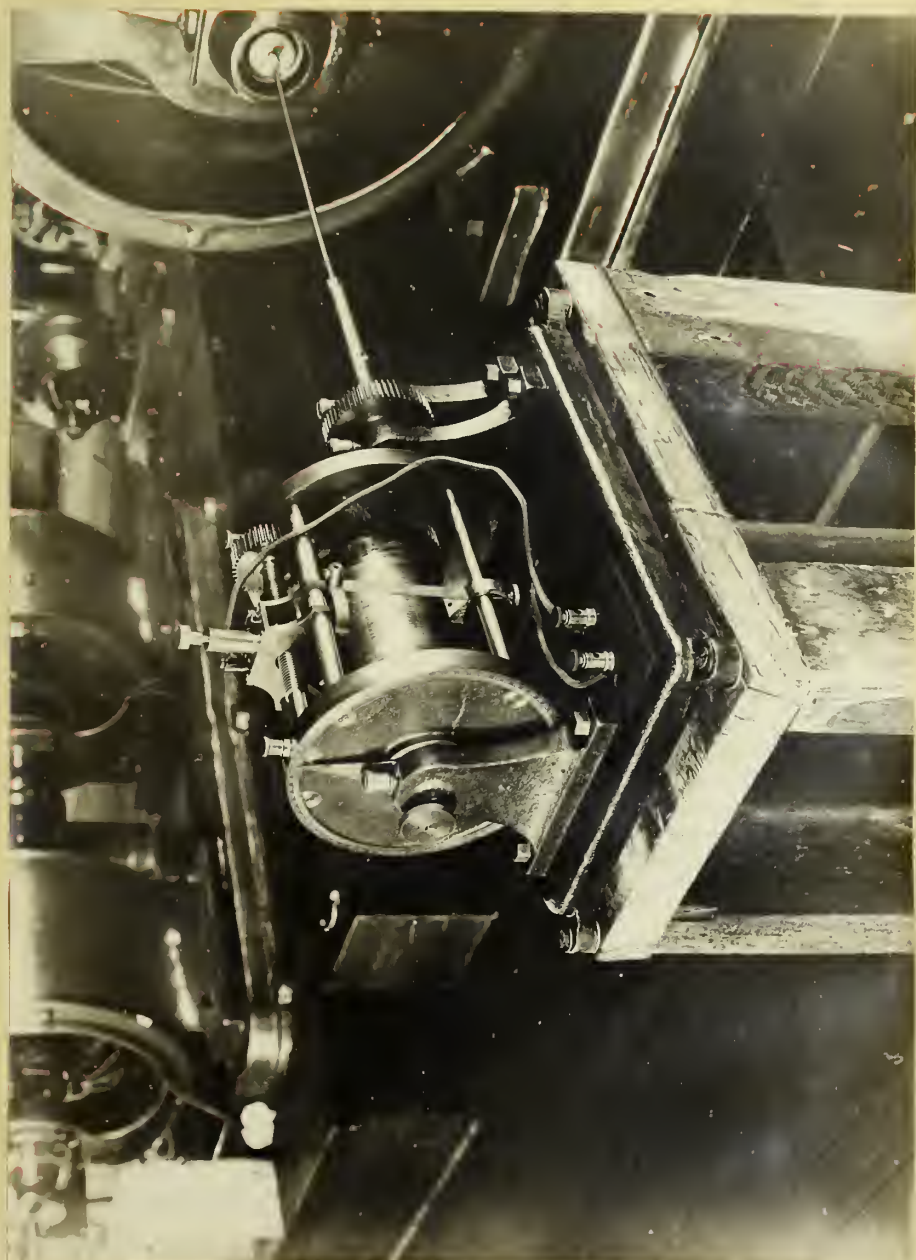


Plate I.

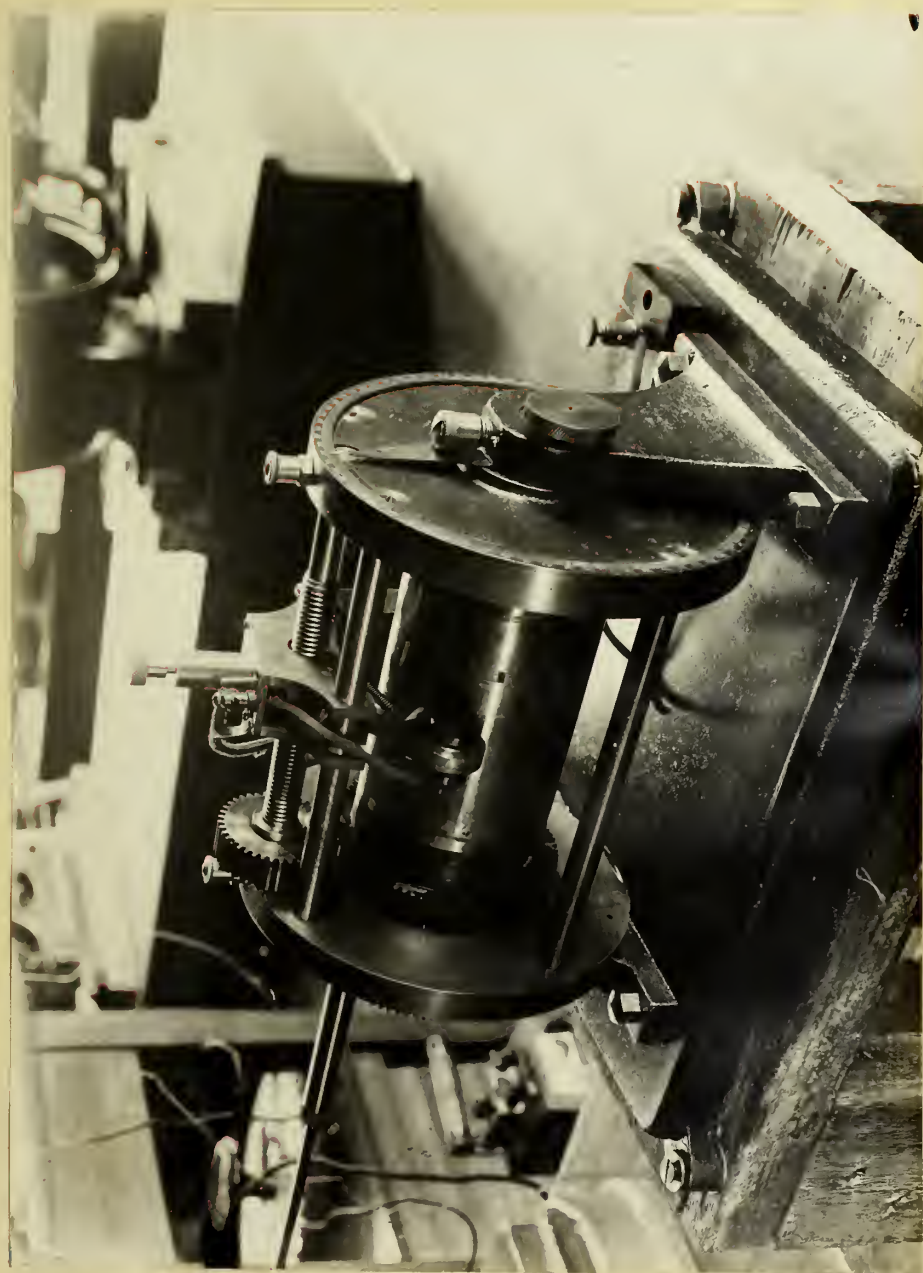


Plate II.

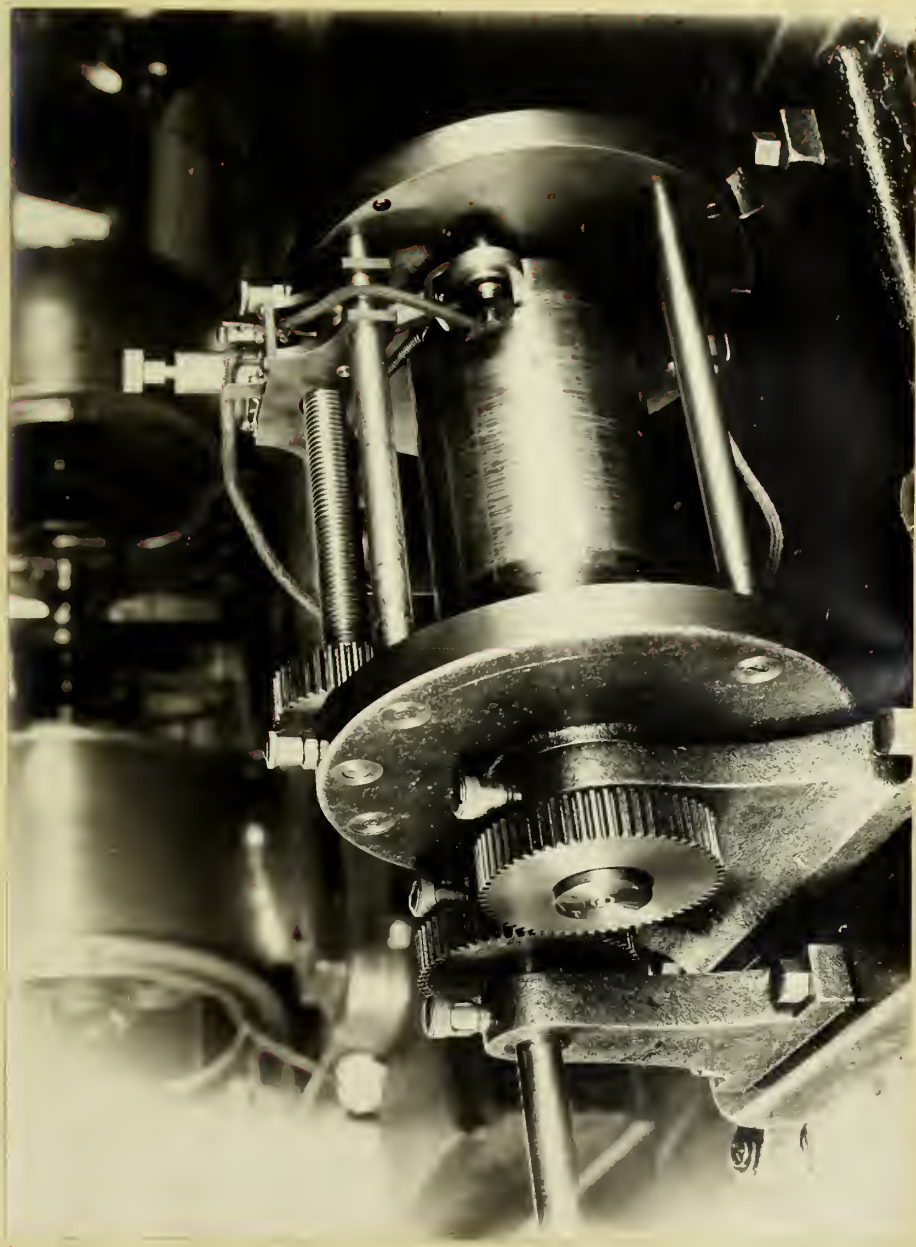


Plate III.

high a speed when attached to a two pole, sixty cycle alternator. These gears are shown in Plate I-B at A and B. The gears were calculated so that the sum of the teeth in any set was 120. The distance between the centers of the main shaft and drum shaft was made three inches and this made it unnecessary to use an intermediate gear since the diametral pitch of the gears was 20. A table of these gears is given below.

TABLE I.

Poles	Shaft Gear A.	Drum Gear B.
2	40	80
4	60	60
6	72	48
8	80	40

Only six gears are required for these changes, i.e. gears with 60, 60, 40, 80, 72, and 48 teeth. Photographs of the switch attached to a four pole alternator are shown in Plates I, II, and III.

III.

The first tests of the switch were made by running it attached to an alternator and closing the circuit through the voltage element of an oscillograph. The diagram of the circuits used in making the tests is shown in Plate IV. An auxiliary contact was arranged to close the oscillograph shutter trip circuit by the motion of the carriage just before the switch closed the circuit on the element. The oscillograph

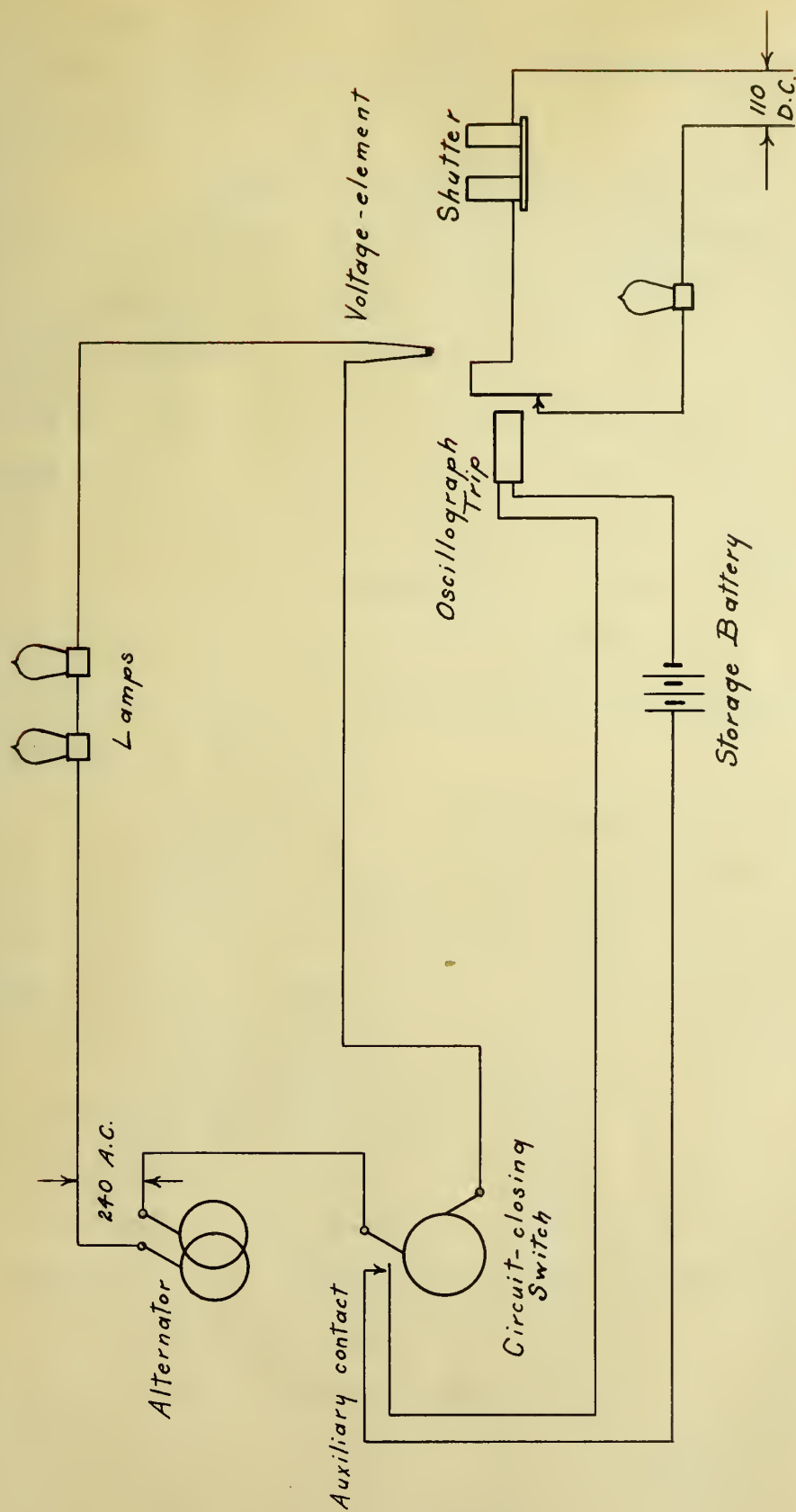


PLATE IV

Connections for testing switch.

drum was run at such a speed that there were only three cycles on the film in order to make more accurate angular measurement possible.

A number of oscillograms were taken with the carriage in the same place to determine a calibration point. The angle of closing was measured from the oscillogram by means of a wave micrometer. The carriage was then set at different angles and the change in closing points measured from the oscillograms. The results are given below in Table II and prints from some of the oscillograms are shown in Plates V, VI, and VII.

As may be seen from the table the maximum error was about 5°. This cannot all be attributed to the switch, as there are chances for error both in the oscillogram itself and in its measurement.

The results of these tests were satisfactory in so far as accuracy of closing was concerned but it was found that the resistance of the contact between the roller and drum was high enough to cause serious sparking as soon as any appreciable amount of current was sent through it. The effect of this may be seen in Plate VI. It would also have been impossible to take anything except a single phase short circuit with only one roller on the machine. A three pole knife switch was arranged to be closed by a magnetic trip and this was tested as a relay operated by the circuit closing machine. It was found to be entirely unsatisfactory as its time period varied over limits as large as a cycle, thus nullifying the effect of the circuit closing device entirely. This made it necessary to

TABLE II.

Set for	0°	180°	Diff. 1	0°	Clos.	Diff. 2	$\frac{\text{Diff. 1}}{\text{Diff. 2}}$	Angle	Result
1. Calibration	22.0	99.3	77.3	22.0	5.0	17.0	.220	-39.6	Average = 39.1°
2. Calibration	6.0	82.8	76.8	99.3	82.8	16.5	.215	-38.7	
3. 45° from cal.	10.0	87.3	77.3	43.8	10.0	33.8	.437	-78.8	
4. 90° from cal.	1.2	77.8	76.6	59.6	5.2	54.4	.712	-128.1	39.7° from cal.
5. 90° from cal.	22.0	97.5	77.5	71.1	17.9	53.2	.687	-123.8	89.0° from cal.
6. Calibration	----*	----*	----*	81.9	30.0	51.9	.660	-119.0	84.7° from cal.
7. Calibration	11.2	90.8	78.6	100.0	47.3	52.7	.671	-121.0	Average = 122.0°
8. Calibration	21.6	98.1	76.5	60.2	9.0	51.2	.670	-121.0	
9. Calibration	11.0	87.4	77.4	92.9	40.7	52.7	.681	-123.0	
10. 90° from cal.	24.4	102.0	77.6	46.1	32.4	13.7	.177	-32.0	90° from cal.

*Could not be measured from oscillogram; assumed same as #5.

Diff. = difference; Clos. = closing point.



Plate V.

Calibration 39.6° from neutral



Plate VI.

Calibration 38.7° from neutral

Showing effect of sparking under roller.



Plate VII.

Set for 90° from calibration; measured 89°.

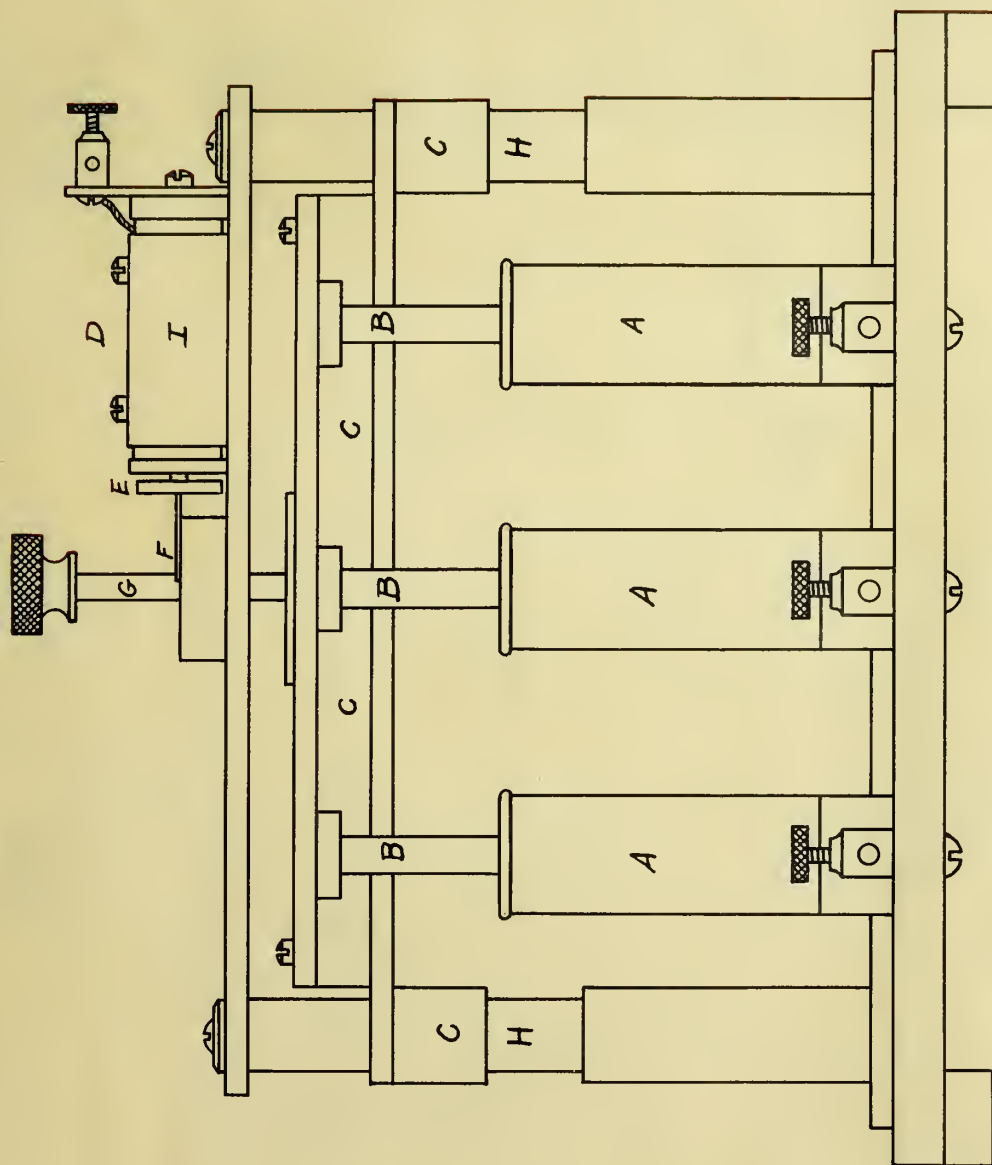
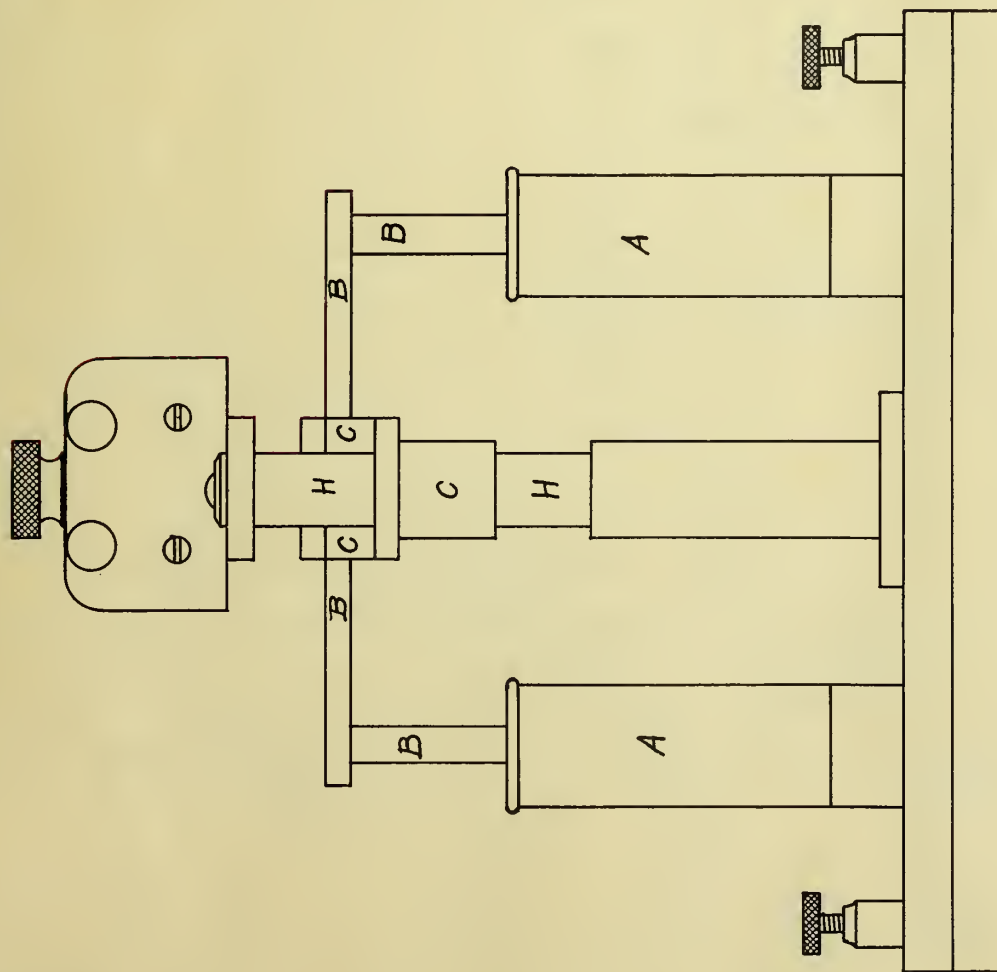


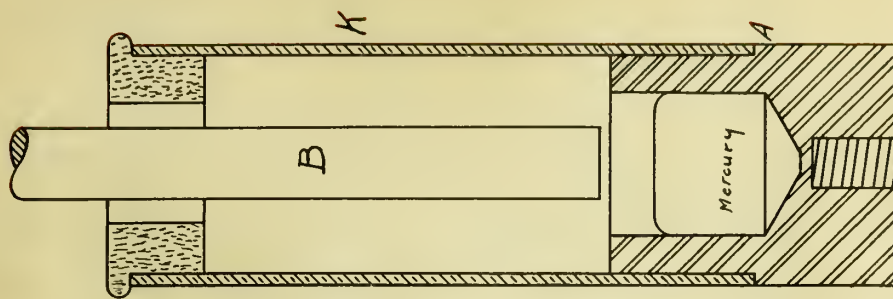
PLATE VIII

Side view of relay.



End view of relay

PLATE IX



Cross-section of mercury cup

construct a relay with a constant time period if the switch was to be of any practical use.

IV.

The reason for variation in the time of closing of the relay switch was variation in the friction of the joint and trip and in the clip contacts. A new relay switch was designed in which the moving portion slid instead of rotating and the clip contacts were replaced by mercury cups. The drawings of this relay are shown in Plates VIII and IX. It consists of six mercury cups A, three of which are connected to the three lines and the other three are joined together for short circuit tests. Three U-shaped insulated metal pieces B carried on the sliding member C fall into these cups and connect them in pairs so that when the sliding part falls, all three lines are connected together. The trip D consists of an armature E which, when actuated by an electromagnet I, pulls a piece of polished sheet steel F out of a slot in a brass rod G connected to the sliding member. A spring causes this member to fall very quickly when it is released. The rods H, H on which it slides were ground and polished very carefully so as to eliminate the friction as far as possible. A photograph of the relay is shown in Plate X.

V.

The tests on the switch and relay together were made in the same manner as those on the switch alone except that the voltage wave was constantly impressed on the oscillograph element with the alternator giving full load current and then

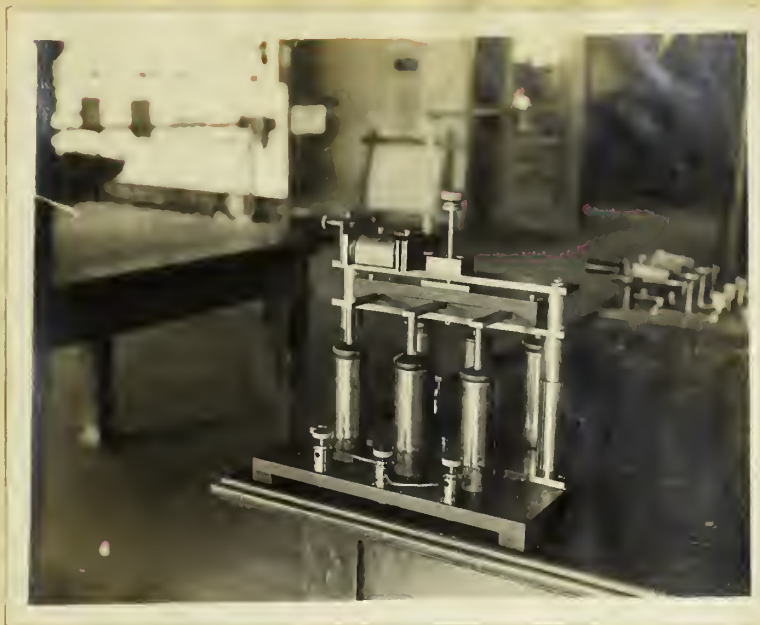


Plate X.

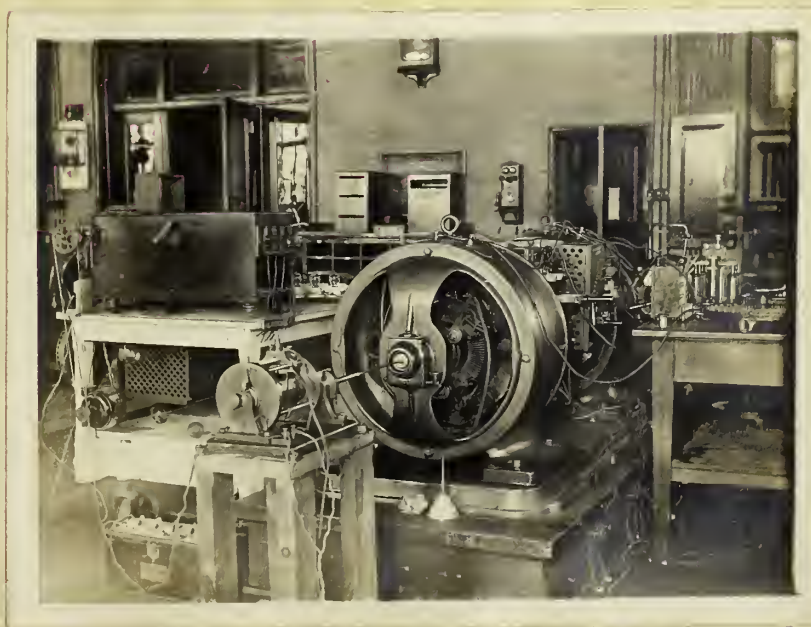


Plate XI.

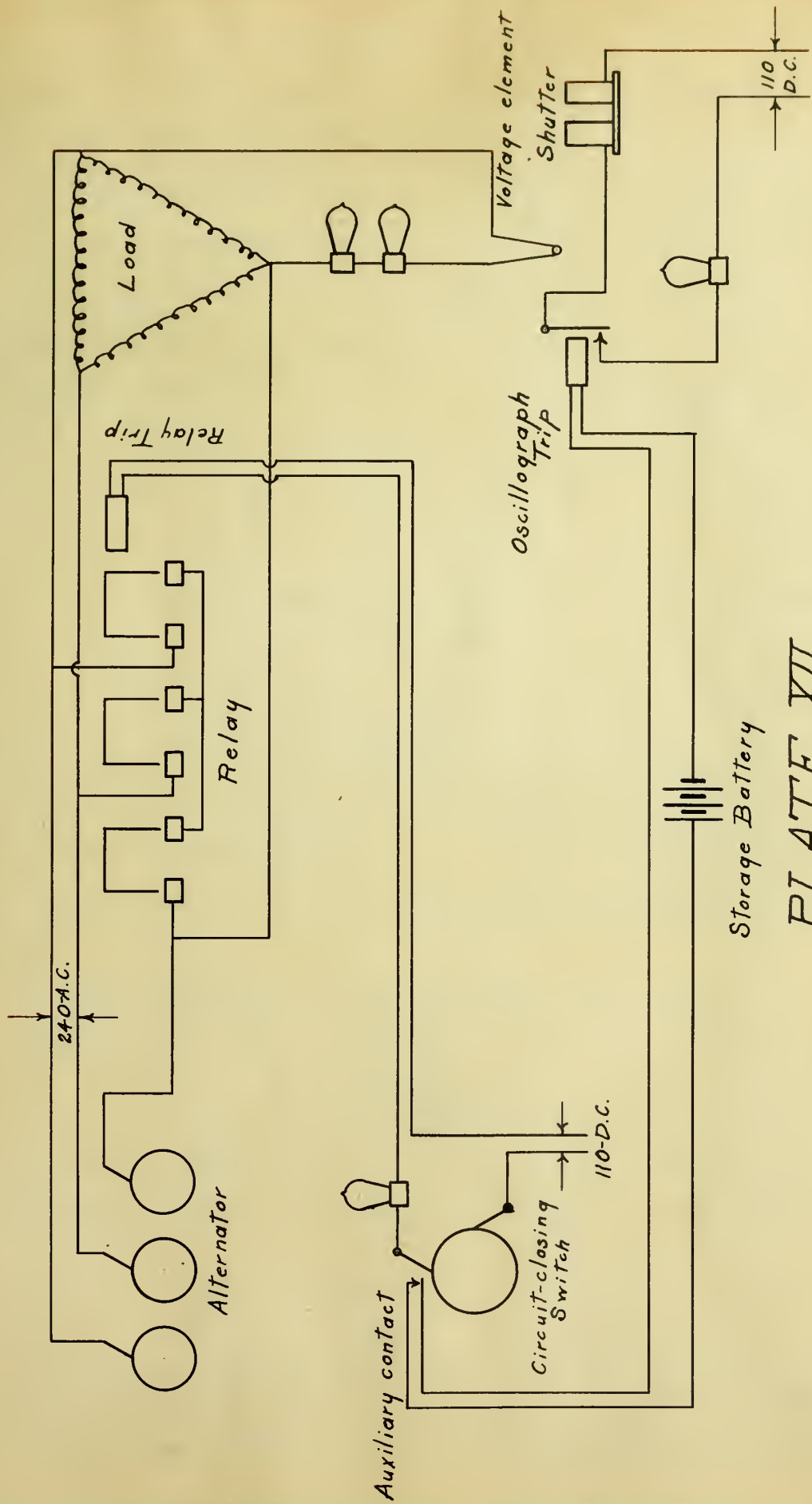


PLATE VII

Connections for testing switch and relay

the machine was short circuited by the relay and the short circuiting points were measured. The instantaneous short circuit current through the relay went as high as 1200 amperes. The mercury contacts were arranged with a brass cylinder K, Plate IX, above them designed to hold oil. With currents up to 200 amperes the closing was very effective with no evidence of arcing but with heavy currents the oil was thrown out of the cup. This was probably due to a film of oil being carried underneath the mercury by the contact rods and being volatilized. The effect was worse with heavy oils than light, but no oil was available which was light enough to do away with it entirely. The final tests were made by leaving the oil out of the cups entirely and the result was quite satisfactory. The mercury levels were adjusted very carefully and tested electrically to be sure that the different rods all made contact at the same instant. A photograph of the set-up is shown in Plate XI. The diagram of the circuits used in making the tests of the switch and relay is shown in Plate XII.

Two oscillograms taken from the relay are shown in Plates XIII and XIV. The difference in short-circuiting points produced by the switch and relay including errors due to oscillograph and measurements is 3.7° . An oscillogram showing a test made with the machine set for closing at zero is given in Plate XV.

VI.

It was found that the switch could be used to measure the reactance of the armature in various positions. A lamp was

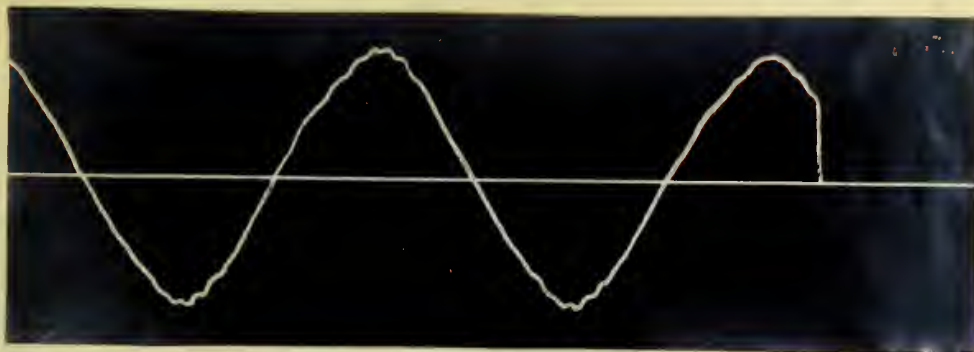


Plate XIII.

Calibration 140.3° from neutral.

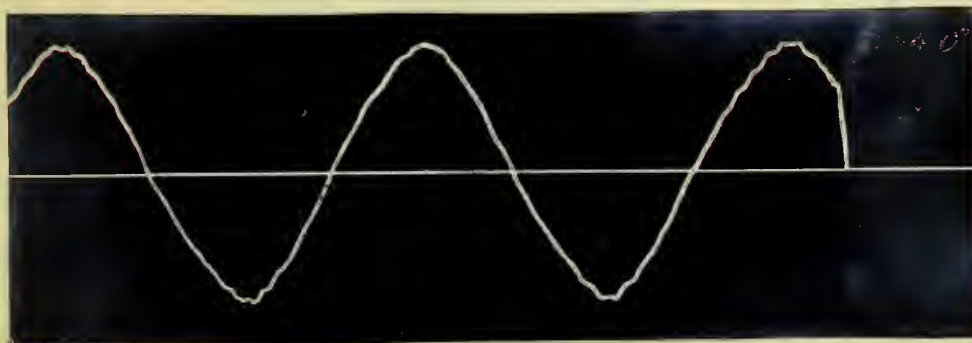


Plate XIV.

Calibration 144.0° from neutral.

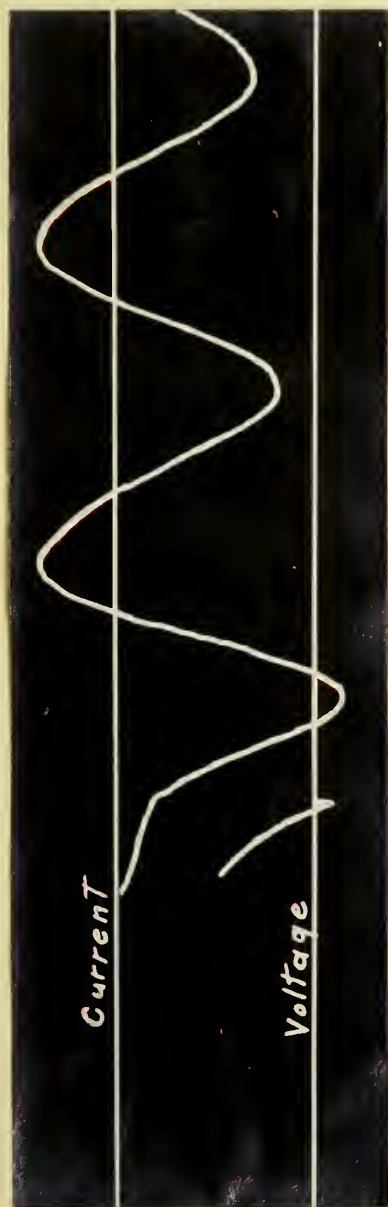


Plate XV.

Set for zero.

connected across the contact roller and drum. The armature was turned until the lamp lighted and the reactance measured in that position. The carriage was then moved around the desired number of degrees and the armature turned until the lamp lighted again and the reactance measured a second time. By this means the angular position of the armature could be determined very accurately. A reactance curve obtained by this means is shown in Plate XVI.

Reactance - ohms

1.5

1.3

1.1

.9

.7

.5

0

20

40

60

80

100

120

140

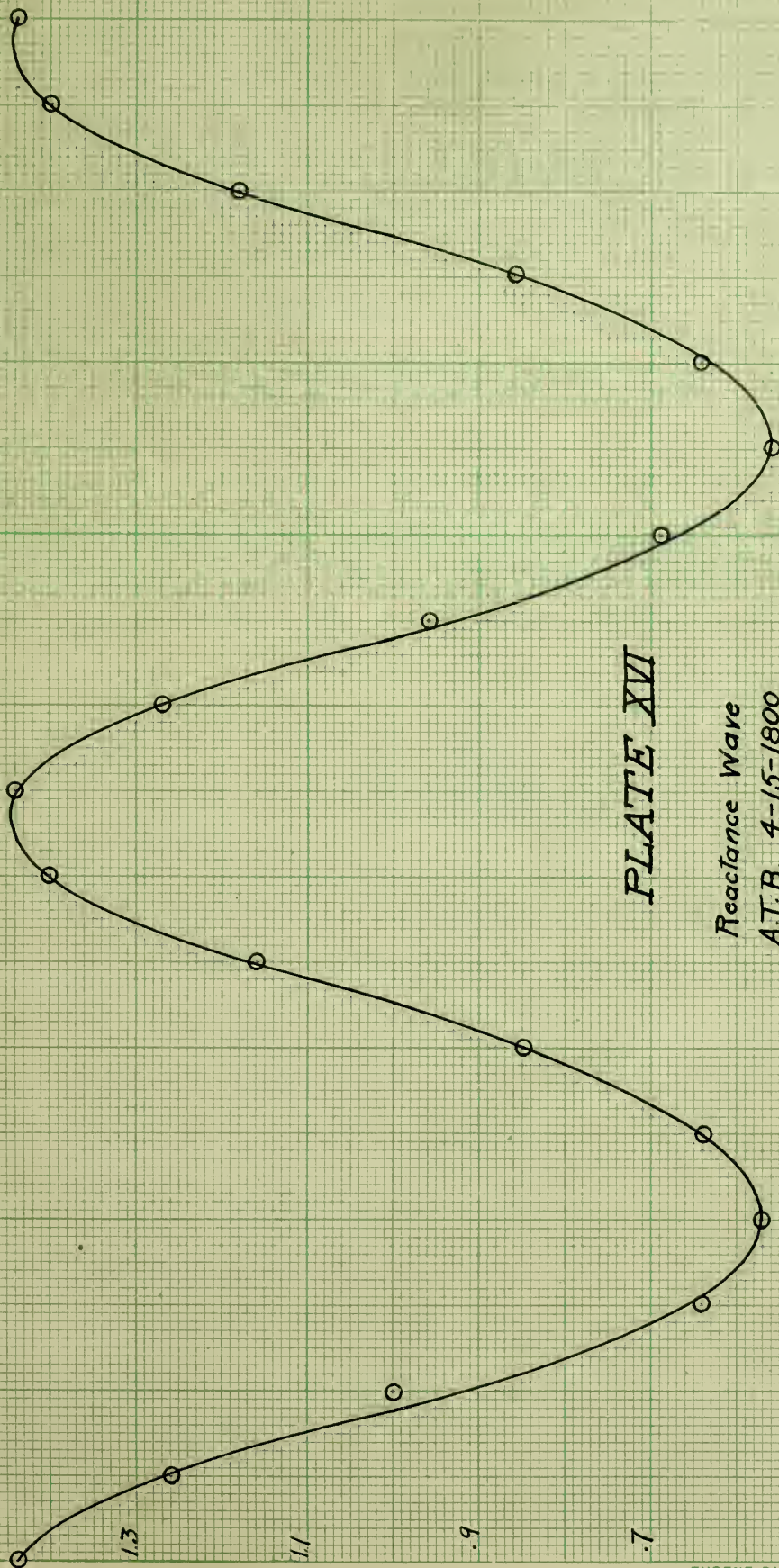
160

180

PLATE XVI

Reactance Wave
A.T.B. 4-15-1800

Mechanical Degrees







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